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Human energy and time spent by women using cooking energy systems: A case study of Nepal

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ABSTRACT

In most developing countries, many rural households use fuelwood and a traditional cookstove (TCS). Women are the backbone of the cooking system, as they mostly manage it. Despite several existing efficient cooking energy systems, households generally do not prefer them. Thus, our aim is to find why this is the case. We estimate the time required and human energy expenditure (HEE) for production of cooking fuel for four alternative cooking energy systems in Nepal, as a case study. The time required to produce cooking fuel for the baseline scenario (i.e. fuelwood and TCS) is 40 h/cap/yr and HEE is 41 MJ/cap/yr. System 2 (charcoal and TCS) has the highest demand for time and HEE. The results suggest that the most efficient system is System 1 (i.e. fuelwood and an improved cookstove (ICS)). However, a woman produces cooking fuel for the whole household, which multiples her time and HEE demand to the household size. This system analysis indicates a significant influence in the selection of cooking fuel due to the HEE and time demand. It concludes that in the future, more importance should be attached to the labour required from women in the cooking energy systems in the development of technological improvements.

1. Introduction

Despite the rapid technological advancements, about 60% of the populations of developing countries and 40% of the global population depend on solid fuels for cooking [1,2]. These solid fuels, like fuelwood, charcoal, animal manure and agricultural wastes are mostly used as primary cooking fuel with traditional cookstoves (TCS) [3]. This is the most inefficient form of a cooking energy system, since TCS has an efficiency of only 10% and solid fuels can lead to deforestation [4,5]. More than 90% of rural households use fuelwood for cooking [6,7].

In developing countries, women play a major role in the selection of a cooking fuel, as they make or collect most of it [8]. They prefer to use fuelwood, since it is easily accessible and economically viable for them. They spend most of their time collecting fuelwoods from forests or nearby areas [9]. However, other than collecting fuelwood and cooking, they also have additional household chores and activities. All these metabolic energy intensive laborious activities go unaccounted for [10]. Previous research suggests that the time investment problem in fuelwood collection can be solved by switching to improved cookstoves (ICS) [9]. Still, there are unanswered questions to the demand of human energy involved in the cooking energy systems.

There are some existing efficient cooking systems using high calorific value solid biomass resources like briquettes and ICS, which are provided through government or non-government projects in rural areas [11,12]. Despite substantial effort, these projects are hardly successful, which is hampering sustainable development in rural areas. Currently, there is a very poor understanding of the subject of fuel-switching for cooking in rural areas [13].

The findings from previous research are important from a technology perspective. However, much less attention is given to the fact that in the production of solid fuels, women have to collect, chop, and carry fuelwood from a forest to their respective houses. After all, households are not only users but also often producers of energy carriers. Other high-energy content solid fuels like charcoal and briquettes require more work in their production. Although there are studies on the increasing energy content in these solid fuels, which are currently more technology specific, much less has been reported on the actual time and metabolic energy required in the production of these solid fuels [14]. It has already been established that South Asian women spend about 374 h on fuelwood

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Abbreviations:

BMR	Basal Metabolic Rate
cap	Capita
CV	Calorific Value
eq	Equations
FAO	Food and Agriculture Organization of the United Nations
HEE	Human Energy Expenditure
hh	Household
ICS	Improved Cookstoves
kg	Kilograms
l	Litre
LPG	Liquefied Petroleum Gas
MJ	Megajoules
PAR	Physical Activity Ratio
TCS	Traditional Cookstoves

collection in households using TCS, while when using ICS they would save about 70 h per year [4]. Although the cooking energy systems in rural areas are operated manually, which includes a lot of time and human energy, these are mostly excluded from an energy balance and life-cycle analysis. However, they are a very important contributor to the analysis, since women have to spend their valuable time and energy, which could be used for other purposes [8].

Metabolic energy is expressed as human energy expenditure (HEE), which is rarely measured and usually excluded from the energy system analysis, despite the fact that, while producing cooking energy, a high amount of HEE is required [15,16]. Other findings pointed out that this could be one of the reasons for the failure of many cooking energy projects [10]. These studies on women and sustainable energy indicate that labour saving technologies mostly fail to include women's time and energy in their designs [17]. Therefore, studies concluded that renewable energy manufacturers fail to identify the importance of time and HEE, which clearly affects the selection of cooking energy [15].

Thus, the main objective of this paper is to assess the time and HEE requirement in the production of different cooking fuels using different cookstoves. In this paper, we have four hypothetical alternative cooking energy systems. We made a cooking energy-balance analysis, which includes time requirement and HEE to produce cooking fuel. The assessment was carried out using Nepal as a case study. This analysis consists of two parts. In the first part, we calculated the time and HEE for the presently existing cooking system in rural Nepal (i.e. the baseline scenario). In the second part, we calculated the time and HEE for the four alternative cooking energy systems. Finally, results were discussed and concluded for different scenarios, on the basis of time and human energy required.

2. Methodology and data

This section presents the cooking energy system that was developed. It consists of four alternative cooking systems to study the time demand and HEE. The system describes all the processes needed to produce useful energy (i.e. the number of MJs of thermal energy produced by fuelwood for cooking. This study follows a system approach, where the present existing cooking energy situation of the case study area (i.e. Nepal) is regarded as the baseline scenario. The hypothetical alternative cooking energy systems are a combination of different ICS and energy fuels. Fig. 1, shows the system description of the different cooking energy systems.

For this study, we assumed that women carried out all the work, which includes the collection and production of cooking fuel for the whole household.

2.1. Baseline scenario

In this baseline scenario, rural households mainly use fuelwood in TCS. The harvested fuelwood is left to dry. The calorific value (CV) of fuelwood is assumed to be 14 MJ/kg dry weight [18,19]. A TCS is assumed to have 10% cookstove efficiency (η_{cv} %) in converting the energy present in fuelwood into useful energy for cooking [20]. The efficiency is much lower, since in TCS most of the heat is lost to the atmosphere. Fig. 1, shows the detailed alternative cooking energy systems considered for the assessment.

2.2. Alternative cooking energy systems

The four alternative cooking energy systems are combinations of different cooking fuels and cookstoves. In System 1, we used fuelwood and ICS. For System 2 and System 3, we considered charcoal as cooking fuel. However, for System 2, we used TCS and for system 3 ICS. In System 3, we used briquettes as cooking fuel and ICS. We chose to only use products of fuelwood as cooking fuel, since fuelwood is the most preferred cooking fuel. Charcoal and briquettes are the next most preferred transition fuel after fuelwood. They are more preferable to use, yet do not change the whole existing cooking system. Moreover, they have a higher energy content than fuelwood. The detailed description of the developed household cooking energy system is given in Table 1.

2.3. Calculation of time demand and HEE

This section presents a brief description of the system boundary and the equations (eq.) involved in the calculation of time demand and HEE.

2.4. System boundary

A basic rural cooking energy system consists of cooking fuel, a cookstove, and labour involved in the production of cooking fuel. The primary cooking fuel is fuelwood, which is collected by women. Our study does not consider any specific cultural diet or cooking procedure in the calculations. It is restricted to the cooking energy fuel used in the scenarios (Fig. 2). The present scenario (i.e. the baseline scenario) is the cooking energy system for which the households in Nepal use fuelwood and TCS. They collect fuelwood from the forest and chop it. For the alternative cooking energy system, we assume that the fuelwood from the baseline scenario is used to make charcoal and briquettes. The charcoal is prepared in a kiln. In this study, kiln operation for charcoal production has been restricted to one type of kiln (i.e. a 200 l drum kiln), since this kiln is affordable for rural people [23]. We further assumed that the briquette is made from the charcoal, which was initially made from fuelwood. Briquettes from agricultural waste are not feasible for this study, because the crop residues are used to feed animals. In our system, a household collects and produces its own cooking fuel, as there is no market available in the vicinity.

2.5. Case study area

Nepal is a mountainous, landlocked and agrarian country. It has an estimated population of about 28 million people and an annual economic growth of 2.7% [28]. About 80% of the population resides in rural areas [29,30]. Nepal's energy sector has been categorised as

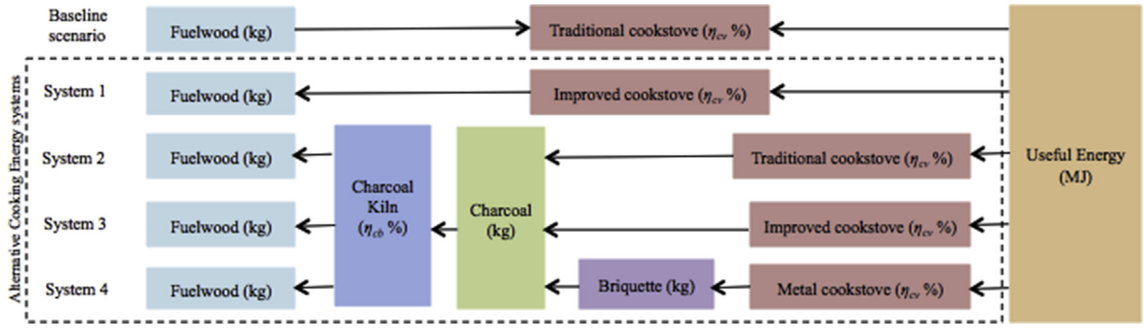

Fig. 1. System description of the developed alternative cooking energy systems.

Table 1
A detailed description of the systems.

Systems	Description of the systems
System 1	In this system, ICS is introduced into the baseline scenario. In our study, we assume that the households residing in our selected area of study uses Mud-Rocket stove for cooking [19]. This improved cookstove has an efficiency of about 25% [21].
System 2	In this system, the low-energy content fuelwood is converted into high-energy content fuel, i.e. charcoal. The calorific value of charcoal is 28 MJ/kg [21,22]. We considered 200-lt horizontal drum kilns to prepare charcoal. FAO considered it as low cost technology for rural people [23]. The charcoal is made in 200-L oil drum. Around 18 kg of charcoal can be obtained per batch using drum kiln [24]. The cookstove is TCS.
System 3	System 3 is a combination of charcoal and ICS. The charcoal production procedure is same as that of system 2. We have used Mud-Rocket stove which has an efficiency of about 25% [21].
System 4	The last system involved briquetting of charcoal. Briquetting is the technique of densification or compaction of loosely packed biomass materials. Since charcoal loses its plasticity during carbonization, it needs a sticking material to enable a briquette to be formed. The charcoal powder is mixed with 10–15% dry clay soil. Dry clay soil is an important component, since it keeps that briquette intact. This means that the briquette contains about 15% binder and 85% of charcoal powder by weight. The calorific value of such charcoal briquettes with the binder is about 22 MJ/kg [25]. The briquettes produced can be used in a traditional stove or a specifically designed briquette stove. An improved briquette stove has much higher efficiency compared to a TCS. We assume that all the households use ICS for rural households which is specifically for briquettes, and the thermal efficiency is about 35% [26,27].

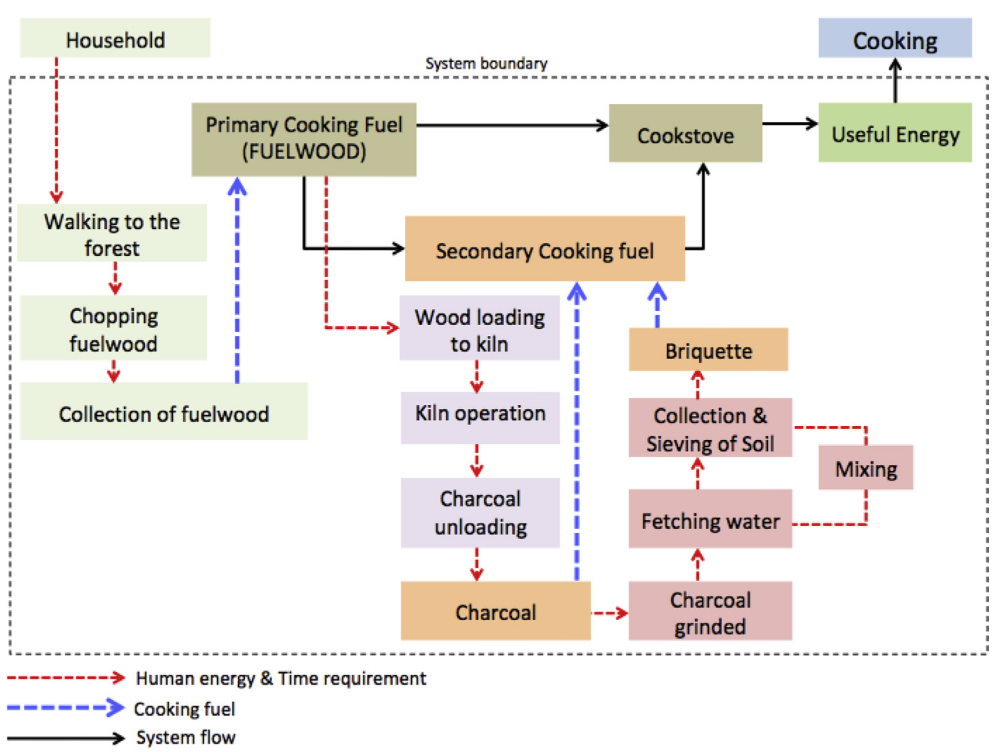

Fig. 2. A detailed description of various activities involved in the production of cooking fuel. The red arrow shows the human and time expenditure in the cooking fuel production, the blue arrow indicates the final cooking fuel produced, and the black arrow shows the process flow of cooking energy used. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

a low energy consumption sector because of its small, inefficient and unreliable energy supply, and it is mostly based on traditional sources [31]. Of the traditional forms of biomass, fuelwood is the most common energy source for households, accounting for 78% of the national energy consumption [32,33]. The majority of the fuelwood is sourced from the forest [34,35] and mostly collected by women and children who spend several hours per day on this, often travelling significant distances, making it very strenuous work for them [36,37]. This study has been carried out in three Eastern mid-hill districts of Nepal, namely, Ilam, Taplejung, and Panchtar.

2.6. Data collection

For data, we refer to the project conducted by WINROCK International: "Promotion of Cooking Stove Use in Nepal [38]" in 2013. The project aimed to investigate the fuelwood consumption, cooking fuel type, cooking devices, and distance and time demand on rural households, depending on their gender and economic and health aspects. The data of this study includes both a survey and a literature review. For the survey, a questionnaire was prepared to collect data on fuelwood consumption, the fuelwood collection source, and the time and distance required to collect fuelwood. Some of the data was secondary data, which was collected from the literature review. Examples of this kind are the data on the physical activity ratio (PAR) and the weight of Nepalese women. The detailed survey data has been shown in Table 3.

The survey questionnaire was developed by the WINROCK officials, and before it reached.

Households, an orientation programme was conducted for local enumerators. The total number of households in the three districts is 132207 [39]. The sampling methodology is taken from "Guidelines for sampling and surveys for CDM Project Activities and Program of Activities (version 2.0) [40]". We used a stratified random sampling method to determine the sample size, since it is more precise. Our calculation (Appendix A) shows that this survey covered a total of 175 households from the three districts.

Time and distance required in the collection of fuelwood are obtained on the basis of the memory of women in the survey. Since our study aimed to assess the four scenarios of the developed hypothetical model, data is not required to be very precise. The model is robust and can be used for any country irrespective of any geographical conditions.

2.7. Fuelwood demand and number of trips

For the baseline scenario, we derived the energy required for cooking from the amount of fuelwood used, its calorific value and cookstove efficiency. The useful energy demand in MJ per person annually, is calculated using the following equation:

$$\mathrm{E_c} = \left(\frac{w \times cv \times \eta_{cb}}{n}\right) \tag{1}$$

where $\mathrm{E_c}$ is the useful energy demand (MJ/cap/yr), w is the weight of the fuel consumed (in kg/cap), cv is the calorific value of the fuel produced (MJ/kg), n is the number of people in the households (cap) and η_{cb} is the efficiency of cookstove used for cooking in the household (%). The useful energy demand is kept constant for all the systems (Fig. 2), and thus, one can calculate the quantity of fuelwood that women collect in a year. The quantity of feedstock (fuelwood) required for the fuel production is given by:

$$F_e = \left(\frac{E_c}{cv \times \eta_{cv} \times \eta_{cb}}\right) \text{kg} \tag{2}$$

where F_e refers to the amount of feedstock (kg), E_c is the useful energy demand (MJ), cv is the calorific value of the fuel (MJ/kg), η_{cv} represents kiln efficiency (%) and η_{cb} is the cookstove efficiency (%).

The energy spent in fuel gathering depends upon the number of annual trips women make to gather fuelwood. The number of trips relies on the quantity of fuelwood collected in one trip. In this study, we assume that the whole fuel conversion process is done in the house itself but not at the site from where fuelwood is collected. With the available information, we calculated the number of trips required as follows:

$$N_t = \frac{F_e}{Q_f} \tag{3}$$

where N_t is the average number of trips taken per year to collect fuelwood, F_e refers to the fuelwood consumed in a year (kg) and Q_f represents the quantity of fuelwood collected in one trip (kg).

The time demand is determined by using eq. (4), which is given below:

$$T = N_t \times T_c \tag{4}$$

where T is the time spent in collection of fuelwood (hrs/yr), and T_c is the total time required for one trip (hrs).

2.8. Human energy expenditure (HEE)

The FAO has defined HEE as the average amount of energy spent, in a 24hr period by an individual or a group of individuals [41]. Thus, it can quantify the daily calorie expenditure of rural women in various activities.

In this study, the measurement unit HEE is used to calculate the human energy expended while producing cooking energy fuel. The energy expenditure of an adult population is mainly determined by physical activity and body weight [42]. The difference in physical activity can be estimated by using the energy cost for the physical activities and the time allocated to those activities. To account for differences in body size and composition, an individual's Basal Metabolic Rate (BMR) can be estimated. Thus, the energy expenditure of a given activity for an adult individual can be calculated using PAR and BMR values [41]. BMR is calculated using FAO equations based on sex, age, and weight [41]. In our case, we have used the BMR formula for women aged between 18 and 30 yrs.

$$BMR = (0.062 \times weight) + 2.036 \tag{5}$$

where, BMR is the Basal Metabolic Rate (MJ/day) and weight is the body mass of the person in kilograms (kg). In Nepal, household activities are mostly carried out by women. There are no distinctive ages or weight ranges during or in which a woman has to handle household activities. However, in most cases yonger women do household chores, since it requires a lot of energy [41, 43]. For this study, we took the weight of women to be 57.7 kg as the standard weight, since the average weight of an adult Asian woman is about 57.7 kg in other studies [44].

BMR is usually expressed as the unit of a day. Since the time required for the production of cooking fuel is in hours, we take BMR in MJ/hr. The equation for calculating human energy expenditure for an activity can be calculated by using eq. (2).

$$HEE = \{PAR \times Time\ (hour) \times BMR\ (MJ/hr)\}\text{MJ} \tag{6}$$

In the above equation, HEE is in MJ, the PAR value is based on the activity involved in the cooking fuel production, and time (in hours) is the time expenditure of each activity. The activities involved in the production of cooking fuel are detailed in Table C1 (Appendix C).

The PAR values for different activities are already listed by the FAO for various physical activities. Not all of the activities involved in fuel production are described in the FAO chart. For our study, we have made a few assumptions relating to the physical activity, similar to those made for the cooking fuel production (Table B1, Appendix B). For example, to prepare a briquette we need water to mix the clay and charcoal. In the FAO, a PAR value is given for fetching water from a well, however water can be collected in many ways, and each way will have a different PAR values. Hence, for this study, we assume that the PAR value for fetching water is consistent with the FAO value. Similar studies have been carried out which are related to fetching water in Mali, West Africa, where the assumption of the PAR is taken to be similar [16].

To produce cooking fuel, an investment of time is required. For the baseline scenario, the time required for fuelwood collection is taken from the survey. The detailed table has been given in Table C1 (Appendix C). The yearly HEE is estimated by multiplying the HEE (from eq. (6)) by the annual number of trips required for fuelwood collection.

2.9. Sensitivity analysis

A sensitivity analysis was performed on the basis of the weight load carried by women. There are many input variables in our studies, but we considered only the fuelwood weight carried by women. The carried weight is an important factor, since a woman has to carry a considerable amount of heavy weight each time. Other variables, like cookstove efficiency and cooking fuel calorific values, will indirectly indicate the change in the fuelwood demand. Hence, almost all the variable changes affect the fuelwood demand (in kg) in some way. This is linked to the number of trips that eventually relates to the amount of fuelwood a woman has to carry.

3. Results and discussion

3.1. Survey data

From the survey data, it was found that on average a woman could carry 41 kg of fuelwood in one trip (Table 2). In order to validate our results, we compared our data with other study, carried out in similar geographical areas like the Eastern Himalayan regions of India. The comparison reveals a similarity with the Himalayan studies. It shows that in both cases the size of households differs by just one member. The fuelwood consumption per capita is almost analogous, and this may be due to the fact that both case studies have similar geographical and climatic conditions. Furthermore, it is interesting to find that women carry almost the same amount of wood. The average time for fuelwood collection was not analysed in the Himalayan case study. In some cases, fuelwood demand is based on geographical conditions. For example, South Africa has a very different geographical condition. However, the average fuelwood consumption per person is about 2 kg/cap/day [45], which is almost equivalent to the Himalayan and Nepalese case studies.

3.2. Fuelwood demand and number of trips

The developed cooking energy system has a combination of different cookstoves and cooking fuels. Details of the calorific value (CV) and efficiency of cookstoves have been given in Table C2 (Appendix C). The improved wood cookstove that is used for System 1 has almost the same efficiency as that of the improved charcoal cookstove used in System 3. The CV of briquettes is less than that of charcoal. It is due to the fact that briquettes are a mixture of clay and charcoal, which decreases the briquette efficiency. However, clay prolongs the cooking time, making it suitable for household cooking [47].

When using eq. (1), it is found that the average final useful cooking energy for the baseline scenario is 1344 MJ/cap/yr (~1.3 GJ). This energy depends on the amount of cooking fuel used and on cookstove efficiency. The yearly fuelwood consumption is 960 kg/cap/yr in the baseline scenario. For the alternative cooking energy systems, we assume that the cooking fuel (i.e. charcoal and briquettes) is made from fuelwood. Henceforth, for our further calculations, we will use 1.3 GJ/cap/yr as the useful energy for System 1, System 2, System 3 and System 4. Interestingly, in the case of System 2, fuelwood required for charcoal production is 1600 kg/cap/yr (i.e. a 66% increase from the baseline scenario). This is because more than half of the energy content of fuelwood is typically used in the carbonization process, and the other half is lost due to the poor efficiency of the stove. With a high efficiency improved cookstove, as is the case in system 3, the charcoal provides the same amount of energy but with less fuelwood consumption (640 kg/cap/yr). Even though briquettes have less energy content per unit weight than charcoal, if a stove specifically designed for briquettes is used, there is less heat loss to the surroundings and thus an increased energy yield. In System 4, the fuelwood demand is 495 kg/cap/yr, which is almost half of that of the baseline scenario. In system 1, the direct combustion of fuelwood in an improved cookstove is the most fuel-saving scenario, with a 60% reduction in feedstock consumption, compared with the baseline scenario. From the FAO, it is clear that 1.14 kg of charcoal is needed to provide useful energy equal to 1 kg of briquettes [25]. As can be seen in Table 1, almost 8 h are required to produce 14 kg of briquettes (i.e. for the manual briquette production of 1 kg of briquettes, one person requires 1.75 h per day).

Fig. 3., verifies the outcome from other studies that, in the production of charcoal, more fuelwood is required. That is, approximately 100 kg of charcoal requires about 700 kg of dry wood [9]. However, a relevant result from Fig. 3 is that when

Table 3
A sensitivity analysis of the weight (fuelwood) carrying factor on time demand and HEE.

Systems	HEE (MJ/cap/yr)		Time demand (hr/cap/yr)	
	Original scenario	New Scenario	Original scenario	New Scenario
Baseline scenario	41	46	40	54
System 1	16	18	16	22
System 2	121	130	160	184
System 3	49	52	64	74
System 4	55	57	88	120

Table 2
Survey data on fuelwood collection.

	Survey	Other study [46]
Average size of household	6	5
Average fuelwood consumption per capita (kg/cap/day)	2.6	2.5
Average amount of one head load of wood carried (kg)	41	49
Average time for fuelwood collection (hrs/trip)	1.7	–

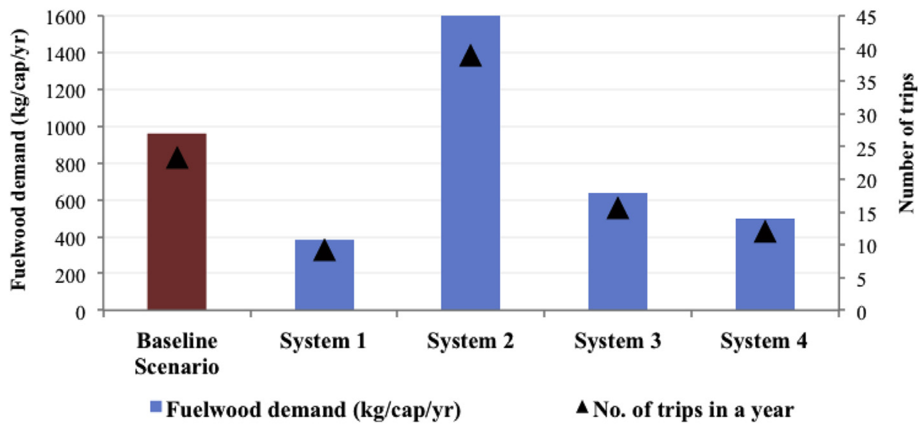

Fig. 3. Fuelwood demand and the number of trips required for its collection for different cooking energy systems.

fuelwood is used with ICS, it happens to demands less fuelwood than other systems. This is a very significant result, as other studies have labeled fuelwood the least efficient of all solid fuels.

We found that with a higher demand for fuelwood, the number of trips needed for fuelwood collection also increases. Women make over 23 trips a year in the baseline scenario. In System 1, when TCS is replaced by ICS, only nine trips are needed to collect the necessary amount of fuelwood for meeting the annual energy demand per capita. However, the number of trips increases to 39, if the fuel source is switched to charcoal with TCS in system 2. Nevertheless, with the use of charcoal in an ICS (i.e. System 3), the frequency of fuelwood collection is reduced by more than half compared to charcoal with TCS (i.e. System 2). In system 4, briquetting further reduces the number of trips taken to collect the wood. However, System 1 requires the least number of trips per year.

3.3. *Energy expenditure and time demand*

The human energy required for feedstock gathering and cooking fuel production is determined using BMR, the time spent on different activities and the energy cost. Fig. 4. shows the energy expended and the time invested by women in the production of fuels from fuelwood. The energy expenditure was calculated by using eq. (6), where a holistic approach to the cooking fuel production chain is taken into consideration. The result shows that the transportation stage (i.e. carrying wood) consumes most of the women's metabolic energy. This is reasonable, as women have to carry a heavy load of fuelwood and walk to their homes. We assume that the women do not increase the amount of fuelwood they collect in one go, hence the 41 kg woodlot is kept constant.

In the baseline scenario, women have to expend their metabolic energy only for fuelwood collection and production, which amounts to a total of about 41 MJ/cap/yr. It is interesting to find that it requires 41 MJ of the physical energy of a woman to produce 1.3 GJ of cooking energy for a household. Earlier studies calculated that the average daily energy expenditure of women is about 8 MJ (excluding cooking activities) [48–50] for rural Indian women. Similarly, for rural women from South Africa, it is about 8 MJ/day [51], and for Mexican women it is about 9 MJ/day [52]. Therefore,

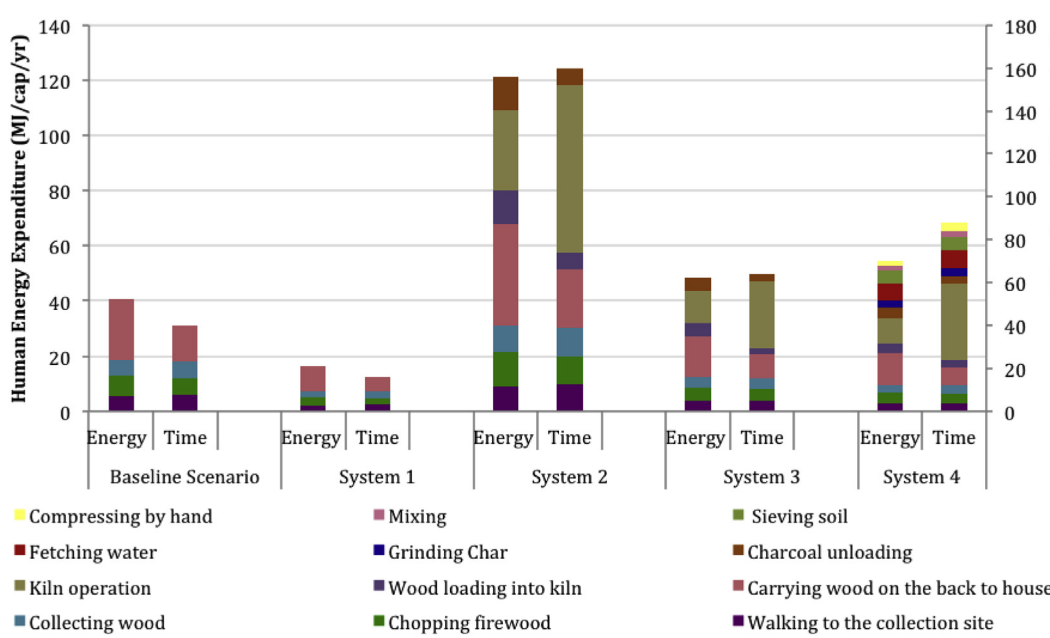

Fig. 4. The energy expenditure of and time demand on woman in the production of cooking fuel for the various cooking energy.

the average daily energy expenditure of rural women from different parts of the world is quite similar. Thus, in our case study, we assumed the total energy expenditure of a rural Nepalese woman to be 8 MJ/day. This means that annually almost 3% of women's energy is spent on producing cooking fuel. When we break the HEE and the time demand for all of the activities involved in the baseline scenario down, we find that carrying wood from collection site to home requires the most energy and time. It requires a HEE of approximately 22 MJ/capita/yr and time expenditure of about 16.4 h/capita/yr, and it is followed by chopping fuelwood, which needs human energy of about 8 MJ/capita/year and the time expenditure of 7.7 h. The important point to note from the baseline scenario is that chopping wood requires less time than collecting fuelwood and walking to the collection site, while the human energy demand for chopping wood is higher than that for collecting it.

For System 1, when ICS is introduced to the baseline scenario, the human energy and time demand almost halves compared to the baseline scenario. In the case of System 1, the human energy demand for carrying wood back home is least amidst the entire developed systems (i.e. 9 MJ/capita/yr and time demand is 6.6 h/capita/yr).

The next highest demand for human energy and time is for the operation of the kiln in System 2, System 3 and System 4. This is because when charcoal is in the kiln, people are still required at the site, to move and watch the kiln to ensure no over-heating of feedstock or other problems arise. This is an important finding because we may expect that no extra human activity is involved when the kiln is operating. Actually, the kiln operation needs less human energy, but as the charcoal making process requires a lot of time, the aggregate value of human energy demand rises. Among the three systems, System 2 requires more human energy and time for kiln operation than the other two systems (i.e. System 3 and System 4).

In a further breakdown of the activities involved in System 2, System 3 and System 4, it is found that the whole operation system of charcoal production (i.e. charcoal loading, kiln operating and charcoal unloading) demands more energy and time than other activities. The total time demand for System 2 is about 160 h/cap/yr, and HEE is 121 MJ/cap/yr. Observing its activities closely, we found that the highest HEE is required for carrying wood (i.e. 37 MJ/cap/yr) with a time demand of 27 h/cap/hr. Most of the time demand in System 2 is for operating the kiln i.e. 78 hr/cap/yr. Operating the kiln requires the highest amount of time out of all of the activities involved in System 2. System 3 requires a total time of approximately 64 MJ/cap/yr and HEE of about 49 h/cap/yr. The total time and HEE demand of System 3 is almost half that of System 2. The reason for the sharp decrease in time and HEE is due to the lower demand for fuelwood (Fig. 3). In the case of System 4, the fuelwood demand is less and it has an efficient cooking energy system (i.e. briquettes and a metal ICS). However, more energy and time are required than in System 3. This is because more activities are involved, which eventually increase the time and HEE. In practice, charcoal has a high CV, followed by briquettes and then fuelwood. Rationally, researchers assume that the selection of cooking fuels are preferred accordingly [53]. However, in this study the efficiency of the systems related to time and HEE has a very different result. Fuelwood used in ICS (i.e. in System 1) is the most efficient with regard to time and HEE. ICS plays an important role in saving time, human energy and thermal energy. Studies in other parts of the world also show that the introduction of ICS has eventually lowered the fuelwood demand. In Peru, the fuelwood consumption was 2 kg/cap/day while using TCS, but changing cookstove to ICS saw the fuelwood consumption drop by 38%, and the same holds true for India [54]. People living in rural areas mostly earn their livelihoods from agriculture, however, they try to diversify their income source and reduce their vulnerability [55]. Thus, saving time by using efficient cookstoves will eventually result in more income options for rural households, and make them more self-sufficient.

Until now, the estimates have been made per capita. As stated earlier, a woman does all of household chores, hence she collects fuelwood for the entire household. The yearly fuelwood consumption per person is about 960 kg for the baseline scenario. From Table 3, we know that the average household size of our case study area is about 6 persons per household. Since a woman collects fuelwood for the entire household, she has to collect 5664 kg/hh/yr for the baseline scenario. This is same for the other systems as well. Similarly, the HEE of and time demand on a woman will be almost 6 times the present calculations. The total time demand on a woman to collect fuelwood for the household is about 240 h for the baseline scenario. When the household uses ICS with fuelwood (i.e. such as in System 1), then the time demand is 96 h/hh. A woman saves about 143 h per year by using ICS. System 2 demands the highest time (i.e. 960 h/hh and the energy of about 727 MJ/hh) of a woman. However, by using ICS with charcoal (i.e. System 3), a woman saves 576 h and 436 MJ per year compared to System 2. This shows the magnitude of labour and time that a woman has to invest only in the cooking system and how much she can save by using ICS.

This hypothetical model of alternative cooking energy systems gives an insight into the time demand on and HEE of the rural Nepal cooking energy system. However, this model is valid for other countries as well and can be used for a time and HEE calculation.

In section 4.4 a sensitivity analysis is carried out to check on how the weight load carrying by a woman affects the time and HEE.

3.4. Sensitivity analysis

The model was further analysed to determine the contribution of the input parameters to the output variability. This was done using a sensitivity analysis (Table 3). In our study, the main parameter is the fuelwood weight load that a woman carries. According to the survey data, Nepalese women carry about 41 kg of weight load from a forest to their house. For our sensitivity analysis, we assumed a lower weight than the survey (i.e. 30 kg of fuelwood), since 41 kg is already a heavy load to carry, thus, we made an analysis for a lower fuelwood load. The assumption of 30 kg was made on the basis of other studies [47,56]. This change means that the PAR value also changes, as PAR is directly linked to the amount of weight a woman carries. We found that with a decrease in weight load, the overall HEE for both the baseline scenario and System 1 increase by 13%, but the most interesting result is that the time demand soars by 37% for the baseline scenario, as well as in System 1 and System 4. Even though we changed the weight load carried by women (i.e. 30 kg), the useful energy remains same (i.e. 1.3 GJ/cap/yr). However, the number of trips increases, as women have to travel more to get fuelwood. The HEE for System 2, System 3 and System 4 has a comparatively smaller percentage change, because of the inclusion of technology like charcoal kilns in the production system. The weight load change had the most significant effect on the wood carrying activity. The HEE has decreased by 8% for all the systems because of the decreased weight load. However, the time demand for the wood carrying activity has increased by 37%. Table 3 describes the effect of change in the weight carrying capacity of a woman.

Even though we included a sensitivity analysis using variable weight, there are limitations to the data used. For example, the calorific value of fuelwood ranges from 13.91 to 19.81 MJ/kg dry weight [19]. For our study, we assume it to be 14 MJ/kg. In rural areas, households harvest fuelwood from any type of tree and store it in a shed to dry. Even then, there is some moisture left which decreases the heating value of fuelwood. Since, our study is at household-level and not industrial, hence we considered the lower CV. This study also used very specific cookstoves such as a mud-rocket stove and cooking fuel like charcoal and briquettes. At present, our survey site households use fuelwood for cooking, thus we restricted our alternative source of fuelwood and we did not employ the use of other, more efficient cooking fuels like kerosene or liquefied petroleum gas (LPG). This disparity of assumptions does not significantly affect on our study, as we aim to understand the relative effect of time and human energy in the selection preference of cooking fuels.

4. Conclusion

This paper quantifies the time and human energy required for different developed cooking energy systems. Our study considers the most frequently mentioned alternatives for traditional open-fire cookstoves, which are charcoal, briquettes and improved cookstoves. These systems require more activities than collecting and chopping fuelwood. It is found that these activities demand more time and human metabolic energy than the traditional cooking system. At present, a woman requires a HEE of about 41 MJ/cap/yr and 40 h/cap/yr of time to produce fuelwood. Introducing ICS in the present scenario saves about 60% of time and energy. When ICS and high-energy content cooking fuel is introduced, it requires 88 h/cap/yr and 55 MJ/cap/yr. Given the fact that these Nepalese women are already engaged in other household chores, which are time demanding and physical-energy consuming, these additional requirements of time and energy to produce cooking fuel could be one reason why alternative cooking energy systems are not preferred by local communities. However, this is applicable for any developing country where households are still using solid fuels and TCS for cooking. Thus, new and modified cooking energy systems can only be successful and beneficial when their impacts on the time and energy expenditure of women are taken into account as well. Therefore, this analysis highlights the accounting method of energy analysis for a cooking energy system, and it reflects on how human energy and time contribute to the preference in cooking fuels.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.energy.2019.06.074.

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